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DISCUSSION OF A PELTON WATER-WHEEL TEST MADE AT THE UNIVERSITY OF WISCONSIN.

By CHAS. I. CORP, University of Kansas, Lawrence.

THIS discussion is the result of a series of tests made at the University of Wisconsin in the summer of 1908. The work was a continuance of an investigation by Prof. D. W. Mead to find, if possible, an algebraic equation between the head, horse-power and revolutions of a water-wheel.

He shows in his book on Water Power Engineering some relations between discharge, head, velocity-ratio, etc., which hold for the low-head experiments on which he bases his conclusions.

It is the purpose of this paper to show that, for the Pelton wheel at least, these relations hold for higher heads, and also to work out the equation spoken of above for the wheel used.

RELATION OF HEAD AND DISCHARGE.

We know in the case of the nozzle of a Pelton wheel—

(1) $q = ca\sqrt{2gh}$

where q = discharge in cubic feet per second.
c = coefficient of discharge.
a = area of the nozzle.
g = force of gravity.
h = head in feet on the nozzle.

If the buckets of the wheel are sufficiently removed from the nozzle not to affect its discharge and the coefficient of the nozzle is a constant, the discharge will vary as the square root of the head. Figure (1) shows this relation nicely. The experimental points were first plotted, using the square root of the heads as the vertical ordinates and discharges as the horizontal ordinates. If the relation sought holds true these points will lie on a straight line through the origin. This is shown to be the case. The points for the curve between the heads and discharges were taken from this straight line. The points indicated by circles along this latter curve are experimental points.

RELATION OF RATIO (ϕ) AND EFFICIENCY.

Theoretically, the velocity of the buckets of the Pelton wheel should be one-half the theoretical or spouting velocity of the water to work most efficiently. Actually, due to eddies and friction of the water in the bucket, and to the fact that the reversed stream of water must clear the next bucket, this ratio is something less than one-half.

It is evident efficiency will fall off as we either increase or decrease the value of the ratio of bucket velocity to spouting velocity from this most efficient value.

In figure (2) the values of the ratio of bucket velocity to theoretical or spouting velocity (called Φ) have been plotted horizontally and the efficiencies vertically for every increase of 10 feet in head between 20 and 157.7 feet. A single line averaging the heads above 60 feet has been drawn. It will be noticed the points for any one head may fall both above and below this line, so that for the practical working limits of the wheel the efficiency varies as the ratio (Φ).

RELATION OF HORSE-POWER AND HEAD.

The theoretical horse-power of a wheel $= \frac{wh}{550} = \frac{qh}{8.8}$, where (w) = weight of discharge in pounds per second.

(3) The actual or brake horse-power $= P = \frac{qhE}{8.8}$, where (E) = efficiency.

Combining (1) and (3):

(4) $$P = \frac{ca\sqrt{2g}\,h^{3/2}E}{8.8},$$

It is apparent if c and E are constants, and if Φ remains constant, the power of the wheel will be in direct proportion to the three-halves power of the head, or—

(5) $$\frac{P}{h^{3/2}} = \frac{P_1}{h_1{}^{3/2}}.$$

This reduces to—

(6) $$P = \frac{P_1 h^{3/2}}{h_1{}^{3/2}}.$$

In figure (3) brake horse-power has been plotted vertically and velocity ratio (Φ) horizontally for each of the heads considered in figure (2). The maximum horse-power for each head occurs at practically the same value of Φ ($= 0.45$).

The values of brake horse-power for each head, when $\Phi = 0.45$, was used to plot the curves of figure (4). In figure (4) a straight line was first obtained by using the three-halves powers of the heads and brake horse-powers as coördinates; the curve between head and brake horse-power being drawn from this line, and the experimental points then put in. This curve shows the brake horse-power will vary as the three-halves power of the head when Φ is a constant.

In equation (6), if we make $h_1 = 1$ —

(7) $P = P_1 h^{3/2}$ where $P_1 = B. H. P.$ under one-foot head.

That is, the horse-power that can be developed at any head will equal the power at one-foot head multiplied by $h^{3/2}$.

RELATION OF REVOLUTIONS AND HEAD.

The bucket velocity of a wheel is—

(8) $$v^1 = \frac{\pi D N}{12 x 60},$$

where N = Revolutions of wheel per minute.
D = Diameter of wheel in inches.

Also spouting velocity is equal to—

(9) $$v = \sqrt{2gh}\ .$$

Combining (8) and (9):

(10) $$\frac{\ }{v} = \frac{\pi D N}{720 x 8.025 \sqrt{h}} = \Phi.$$

As equation (10) is general, it follows that when Φ is constant—

(11) $$\frac{D N}{\sqrt{h}} = 1841.6\ \phi = \text{a constant.}$$

"The catalogue speed, power and discharge of each series of wheels, as given in the catalogues of the manufacturers, are usually based on the conditions of maximum efficiency and constant Φ.

"From the above considerations it follows that in any homogeneous series of wheels, that is, in any series of wheels constructed on uniform lines and with dimensions proportional, the wheels of the series are designed to run at the same relative velocity, and therefore—

(12) $$\frac{D N}{\sqrt{h}} = \frac{D_1 N_1}{\sqrt{h_1}}.$$

"That is to say: In any homogeneous series of turbines" (true, also, of the Pelton wheel) "the product of the diameter of any wheel (D), and the number of revolutions (N), divided by $\sqrt{h}$, will be a constant, provided Φ remains constant.

"If, in equation (12) $D = D_1$, the equation reduces to—

(13) $$\frac{N}{\sqrt{h}} = \frac{N_1}{\sqrt{h_1}}.$$

"That is to say: The economical speed of any wheel will be in direct proportion to the square root of the head under which it acts.

"If in equation (13) $h = 1$, the equation reduces to—

(14) $$N = N_1 \sqrt{h}.$$

"From which it follows that the revolutions of a wheel (N) for any head (h) is equal to the revolutions (N_1) for one-foot head multiplied by $\sqrt{h}$."*

This relation might also have been shown by means of curves from the test at hand.

EQUATION BETWEEN HORSE-POWER, REVOLUTIONS AND HEAD.

$$\text{(15)} \qquad \text{Brake horse-power} = P = \frac{2\pi rLN}{33{,}000}.$$

where r = Length of brake-arm in feet.
L = Load on the brake in pounds.

We have shown that under the usual assumed conditions of maximum efficiency and constant Φ, $N_1 = N_1\sqrt{h}$ and $P = P_1 h^{3/2}$, so that equation (15) may be written in the form—

$$\text{(16)} \qquad \frac{P}{h^{3/2}} = \frac{2\pi rL}{33{,}000h} \times \frac{N}{\sqrt{h}}.$$

For simplicity let $\frac{2\pi rL}{33{,}000h} = \frac{CL}{h}$, where $C = \frac{2\pi r}{33{,}000}$ = a constant,

and $\frac{N}{\sqrt{h}} = n$ = revolutions per minute under one-foot head.

Plotting the values of $\frac{CL}{h}$ as the vertical ordinates and of (n) for the horizontal ordinates for the various heads previously considered, figure (6) will result. In this as in figure (2) the points for heads above 60 feet fall along a general line, which has been drawn in.

The product of the horizontal and vertical ordinates of any point on this curve will be the brake horse-power of the wheel under one-foot head and having the revolutions indicated by its horizontal ordinate.

The general algebraic formula connecting two variables such as $\frac{CL}{h}$ and (n) is—

$$\text{(17)} \qquad \frac{CL}{h} = a + bn + cn^2 +, \textit{etc.},$$

where a, b, c, etc., are constants.

It was found that an equation having three terms on the right side of the equality sign gave a curve which corresponded sufficiently close to the experimental curve for practical purposes.

The constants a, b and c were obtained by choosing three points on the experimental curve and substituting the values of their coordinates in the general equation above. The resulting three simultaneous equations were solved, giving as the equation of the curve:

$$\text{(18)} \qquad \frac{CL}{h} = .000106 - .0000009376n - .00000000266n^2.$$

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* "Water Power Engineering," by Mead.

Whence, multiplying both sides by (n):

$$(19)\qquad \frac{CLN}{h^{3/2}}=\frac{P}{h^{3/2}}=.000106n-.0000009376n^2-.00000000266n^3.$$

If we now multiply both sides by $h^{3/2}$ we have—

$$(20)\qquad P=h^{3/2}(.000106n-.0000009376n^2-.00000000266n^3).$$
$$=h(.000106N-0000009376N^2-.00000000266N^3).$$

An equation which will apply directly to the wheel tested and to wheels built on the same lines and with dimensions proportional. The same form of equation can be worked out for different makes of wheels.

PRELIMINARY REPORT ON AN INVESTIGATION OF COAL-MINE EXPLOSIONS.

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THE investigation of the causes of coal-mine explosions. of which this is a preliminary report, was commenced in 1906 by the Kansas State Geological Survey. In that year Lawrence Brett, one of the seniors at the University of Kansas, took this as the subject for his graduation thesis, and did a considerable amount of work, with the expectation of continuing the work later. Lack of funds has prevented the accomplishment of anything further until the present year. In the spring of 1908 Prof. Erasmus Haworth, state geologist, decided to devote the larger part of the funds at the disposal of the Survey to a continuation of this investigation. This paper is to be considered as only a preliminary report, as the investigations discussed are not completed and others are to be undertaken. But we desire to make known some of the results which have been accomplished and to make a statement of plans for the future.

The work has been divided into two distinct classes; the first literary, the second experimental. Along the first line, what might be called a literary bureau has been established and an extensive correspondence carried on with many people connected with the coal-mining industry both in this country and in Europe. A list of questions dealing with the subject was sent to a large number of coal-mine operators. Many replies have been received and the results have been tabulated. These questions were intended to elicit all possible information on the conditions of the coal-mining industry in the different coal-fields of the United States, with the idea of learning what conditions may render possible the occur-